PREHEATING AN OTTO CYCLE
ENGINE FOR BETTER FUEL ECONOMY

A THESIS

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Master of Science in Mechanical Engineering

by

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PREHEATING AN OTTO CYCLE ENGINE

FOR BETTER FUEL ECONOMY

Crosland

Approved:

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ACKNOWLEDGMENTS

I would like to take this opportunity to thank Professor R. L. Allen for suggesting the topic and also for his advice and guidance throughout the work. I would also like to thank Mr. T. D. Sangster for his aid in setting up the test equipment.

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LIST OF ABBREVIATIONS AND SYMBOLS

A/F	Ratio of the pounds of air to the pounds of fuel that are supplied to the engine, as computed with the simple orsat.
A/F*	The ratio of air to fuel as computed with the modified orsat.
BHP	Brake Horsepower.
C	The number of carbon atoms in the exhaust gas.
CO	The percent by volume on the dry basis of carbon monoxide in the exhaust gas.
CO_2	The percent by volume on the dry basis of carbon dioxide in the exhaust gas.
CO_2'	The carbon dioxide after the slow combustion in the modified orsat analysis.
CH_4	The percent by volume on the dry basis of methane in the exhaust gas.
C_2H_6	The percent by volume on the dry basis of ethane in the exhast gas.
c	The percent by weight of carbon in the fuel.
C'	The molecular weight of carbon.
Contr.	The contraction of the sample after the slow combustion in the modified orsat analysis.
H	The number of hydrogen atoms in the exhaust gas.
H/C	The ratio of hydrogen atoms to carbon atoms.
H_2	The percent by volume of the dry basis of hydrogen in the exhaust gas.
H_2O	The percent by volume of water in the exhaust gas.
L	The length of the dynamometer arm in feet.

LIST OF ABBREVIATIONS AND SYMBOLS (continued)

N_2	The percent by volume on the dry basis of nitrogen in the exhaust gas.
N'	The molecular weight of nitrogen.
N	The engine speed in revolutions per minute.
n	The percent by weight of nitrogen in air.
O_2	The percent by volume on the dry basis of oxygen in the exhaust gas.
P bar.	Barometric pressure in inches of mercury, absolute.
P man.	Intake manifold pressure in inches of mercury, absolute.
t	The length of a test in seconds.
T1	Temperature in intake port of number 1 cylinder.
T2	Temperature in intake port of number 2 cylinder.
T3	Temperature in intake port of number 3 cylinder.
T4	Temperature in intake port of number 4 cylinder.
T5	Temperature in exhaust port of number 1 cylinder.
T6	Temperature in exhaust port of number 2 cylinder.
T7	Temperature in exhaust port of number 3 cylinder.
T8	Temperature in exhaust port of number 4 cylinder.
T9	Temperature between heater and carburetor.
T10	Temperature in water jacket.
T	All temperatures are in degrees fahrenheit (not absolute).
T wb	Wet bulb temperature in room.
T db	Dry bulb temperature in room.
W	Load on the dynamometer scale in pounds.

LIST OF ABBREVIATIONS AND SYMBOLS (continued)

w   Pounds of fuel consumed during test.

#f/Hr.   The pounds of fuel consumed per hour.

#f/BHP-Hr.   The pounds of fuel consumed per brake horsepower hour.

Π Pi.

CO1, T1, etc. indicates that this is the value for number one cylinder.

PREHEATING AN OTTO CYCLE ENGINE
FOR BETTER FUEL ECONOMY

INTRODUCTION

Purpose:

Much has been written about the effect of the inlet temperature on the power output of an otto cycle engine, and there has been considerable work on the design of hot spots for intake manifolds in order to improve distribution; however, there is very little data on the effect of inlet temperature on fuel economy. It is the purpose of this investigation to determine whether or not distribution is improved by increasing the inlet temperature and whether or not this increase in temperature will give better fuel economy.

Objective:

The object of this investigation is to obtain sufficient data from the operation of a standard multicylinder otto cycle engine to show the effect of increasing the inlet temperature at various speeds and loads. An analysis of the results will be made and curves will be drawn in order to show the extent and the trend of the results.

APPARATUS

Engine:

The engine used was a Continental model Y-69. This engine was designed for stationary use and incorporated a large capacity radiator which maintained a fairly constant water temperature under all loads. (See Figure 1 and 2). Specifications of the engine are as follows:

Bore, inches	2-1/2
Stroke, inches	3-1/2
Displacement, cubic inches	68.5
Compression ratio	6.2
Number of cylinders	4

Ignition:

The ignition system of the engine consisted of a standard point coil arrangement with the current furnished by a battery. In order to eliminate one of the possible variables, the centrifugal advance mechanism in the distributor was locked in one position. The distributor did not have a vacuum advance mechanism. A plate was made with the true degrees of spark advance stamped on it, and was fastened to the block. The pointer mounted on the distributor indicated spark timing. (See Figure 2 F). The spark plug gap was checked often and the plugs cleaned at regular intervals.

Fuel System:

The carburetion system of the engine consisted of a two gallon can resting on a pair of Toledo scales, a fuel pump, and a special up draft carburetor. The fuel fed by gravity from the weighing can to the fuel pump. The carburetor had a variable main jet, the position of which was indicated by a pointer on a plate attached to the carburetor. (See E Figure 2).

Air Heater:

The inlet air was heated by forcing it to pass around a steam coil consisting of approximately one hundred feet of one quarter inch outside diameter copper tubing. (See B Figure 2).

Dynamometer:

The power output of the engine was absorbed by a Taylor hydraulic dynamometer in connection with a pair of Fairbanks scales. (See A and B Figure 1).

Engine Instruments:

Instruments were mounted on the control panel to register the engine speed, manifold pressure, oil pressure, exhaust pressure, and manifold vacuum. (See G, H, I, K, and L respectfully, Figure 1). The room wet and dry bulb temperatures were registered by standard mercury filled bulb thermometers. (See F Figure 1).

Thermocouples:

Thermocouples were placed in each intake port, each exhaust port, the intake of the carburetor, and the water jacket of the block. These thermocouples were made of iron and constantan wires twisted together and welded under an excess of flux in order to obtain a good junction. (See D Figure 2.)

Potentiometer:

All of the above thermocouples connected to a selector switch (J Figure 1) to a Leeds and Norithrup potentiometer. This potentiometer was of the direct reading type with automatic compensation for the reference junction. (See C Figure 1).

Exhaust Sampling Tubes:

In order to obtain a sample of the exhaust gas from each individual cylinder, holes were drilled and taped in the exhaust manifold and a stainless steel tube was inserted into the mouth of each exhaust port. These tubes were connected to a rubber tube by a on-off valve. (See C Figure 2).

Orsat:

The exhaust gases were analyzed with a modified orsat. The orsat used for these test was a Fisher Technical model. This orsat was equipped with three pipettes, a fractional combustion unit, and a slow combustion unit. (See A, B, C, D, E, and F, Figure 3).

Orsat Chemicals:

The chemicals used for absorption in the orsat were mixed according to the specifications of the Mechanical Engineering Department of the Georgia Institute of Technology. They were as follows:

Carbon dioxide - A solution of three hundred and thirty grams of potassium hydroxide in one thousand grams of water.

Oxygen - A solution of twenty grams of pyrogallic acid in forty-five grams of water made up to two hundred and fifty cubic centimeters with the above caustic solution.

Carbon monoxide - A solution of fifty grams of cuprus oxide in two hundred and fifty cubic centimeters of concentrated hydrochloric acid.

The displacing fluid which was used in the sampling bottles and in the orsat burette was a saturated solution of sodium chloride colored with methyl orange and a little hydrochloric acid. This is recommended by White[1].

[1] A. H. White, Technical Gas and Fuel Analysis, (New York McGraw-Hill Book Company, Inc.) pp 1-91, 1920.

TEST PROCEDURE

The operating procedure for gathering the data necessary for calculating the fuel economy and mixture distribution was as follows:

Before the engine was started an overall visual check of the equipment was made and the radiator water and crankcase oil levels were checked. Also, the universal joint between the engine shaft and the dynamometer shaft was oiled, as were the main bearings of the dynamometer and the tachometer generator. In addition, the main steam valve was opened and the line connecting to the engine allowed to warm up.

The engine was started and the water valve to the dynamometer opened slightly. The engine was allowed to run under light load at about eight hundred revolutions per minute until all temperatures settled down and remained constant. During this warm-up period, the fuel weighing can was filled, the potentiometer needle zeroed, and the operating cell of the potentiometer balanced against the standard cell.

After the warm-up period the desired conditions of speed, load, mixture, and spark advance (the spark advance was held at ten degrees before top center for all runs) were established, and again the temperatures were allowed to become constant. During this time, the sampling bottles were connected to the sampling tubes, and the valves opened to allow the tubes to purge themselves.

With all conditions at equilibrium, the test run was started by starting the stop watch and recording the reading on the fuel scales at the same instant. Then the ten thermocouples were read by switching the selector switch to the desired position; after which the three way valves on the sampling bottles were turned so as to admit the exhaust gas to the bottles. While the bottles were filling, the speed, load, manifold pressure, room wet and dry bulb temperatures, and the exhaust pressure were recorded.

When all of the salt solution had been displaced from the sampling bottles, the valves were closed and the stop watch stopped with a simultaneous reading of the fuel scales. When this data had been recorded, it was checked; and if it seemed reasonable, the engine was shut down.

As soon as the engine had been secured, the exhaust gas samples were transferred to the orsat room to be analyzed. The fluid in the measuring burette was raised to the very top and the valve closed. The three way valve on the sampling bottle was then connected to the three way valve on the measuring burette, and with the leveling bottle on the sampling bottle in the up position (H Figure 3) and the leveling bottle on the measuring burette (F Figure 3) in the down position (I Figure 3), the valves were positioned so as to allow the gas to pass into the burrette. When a small amount of gas had passed into the burette, the valve on the bottle was positioned so as to allow the gas in the burette to be pushed out to the atmosphere by raising the burette leveling bottle. When the salt solution reached the very top of the burette, the valve on the bottle was positioned so as to allow more gas to be drawn into the burette by lowering the burette leveling bottle again.

When the level in the burette is well below zero, connection is again made with the atmosphere and the level brought to zero with the level in the burette and the level in its bottle equal. This means that at this point there are exactly one hundred cubic centimeters of pure exhaust gas under atmospheric pressure in the burette; consequently, any decrease in volume may be expressed directly as a percent.

The gas is then passed several times into each of the pipettes, and a reading taken after each pipette. This means that the difference between any two consecutive pipettes is the percent of the gas which was absorbed in that pipette. After the gas has been passed through the fractional combustion unit (D Figure 3), which is at its operating temperature of three hundred degrees centigrade, and the percent hydrogen recorded, the gas is passed again into the caustic solution; any decrease in volume here indicates that all of the carbon monoxide was not removed in the cuprous chloride. At this point the gas is stored in the caustic pipette, and some air is brought into the burette, measured and transferred to the slow combustion unit; the coil in the unit is heated and the gas passed slowly over it. Any reduction in volume due to this slow combustion is recorded as the total contraction. The gas is then passed into the caustic solution again, and this reduction in volume recorded as a separate carbon dioxide reading. This procedure is repeated for each of the four gas samples.

The above procedure is followed for the first eleven tests after which the fractional and slow combustion are omitted from the orsat procedure. Also for the last six tests only one average gas sample from the exhaust pipe was collected and analyzed.

DISCUSSION

This series of tests can be divided into three groups. The first eleven tests (Group A) were used to establish a procedure, and to check the accuracy of the instruments and calculations. The next seventeen (Group B) were run with varying speed, manifold pressure, and inlet temperature; an attempt was made to hold the mixture constant. The last six tests (Group C) were run with varying speed, load, and inlet temperature; while an attempt to lean the mixture to the same degree of smooth operation for each test was made.

For the most part, the accuracy of the instruments is well within reason. The fuel scales could be read to the nearest one hundreth of a pound, and since the total weight of fuel for any run was over thirty hundreths of a pound, the possible error is under two percent. Although the load scales could be read to the nearest tenth of a pound, the possible error must be plus or minus two tenths of a pound, due to changing water pressure and the slow response of the dynamometer. With a load of five pounds, this brings the error to four percent; however, most of the loads were over ten pounds, and this is not too far out of line.

The tachometer was divided to the nearest fifty revolutions per minute; however, it was easy to estimate to ten revolutions per minute, and the slowest test was made at one thousand revolutions per minute. This gives a possible error of one percent. The smallest division on the manifold vacuum manometer was one tenth of an inch of mercury, and on the barometer it was two hundreths of an inch of mercury. With the lowest manifold pressure thirteen inches of mercury, the possible error is under two percent.

Although the smallest division on the potentiometer was two degrees centergrade, the accuracy in measuring the temperature of a hot gas with a bare wire thermocouple is not very good; however, since each couple was in a similar geometric position, and the temperatures involved for the four similar couples is the same. It is reasonable to assume that the relative values between the couples has some significance. Because of this high possible error, no attempt was made to correlate the absolute gas temperatures with any other variable. It was noticed, however, that when the engine had been shut down for some time and all parts had reached equilibrium, all of the thermocouples checked the mercury filled room dry bulb temperature very closely.

By far the most inaccurate part of the entire procedure was the calculation of the air/fuel ratio. A great deal has been written about the correlation between the air/fuel ratio and the exhaust gas analysis. Best[1], Petze[2], D'Alleva[3], and Lockwood[4] have all experimented along this line. D'Alleva makes the assumption the the percentage of hydrogen in the sample is equal to fifty-one hundredths of the percentage of carbon monoxide. On the other hand, Lockwood assumes that the hydrogen is equal to thirty-eight hundredths of the carbon monoxide. Neither of these

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[1] Best, H. W., "Report on Air-Fuel-Ratio Tests", S.A.E. Journal, 25: 532-533, November, 1929.

[2] Petze, C. L., "The Discussion on the Report on Air-Fuel-Ratio Tests", S.A.E. Journal, 25: 534, November, 1929.

[3] D'Alleva, B. A., and Lovell, W. G., "Relation of Exhaust Gas Composition to Air-Fuel Ratio", S.A.E. Journal, 38: 90-98, March, 1936.

[4] Lockwood, E. H., "Exhaust-Gas-Analysis Calculations", S.A.E. Journal, 21: 571-575, November, 1927.

assumptions were verified by these tests.

In an attempt to check the accuracy of the orsat readings, the ratio of hydrogen atoms to carbon atoms in the fuel was computed. Since all of the fuel was drawn from the same drum, it is reasonable to assume that every analysis should give the same hydrogen/carbon ratio. The results of this check may be seen in Figure 4, or Figure 5 shows the correlation between the air/fuel ratio as computed by the complete analysis and that computed by the simple orsat. Since the primary concern was with variation in distribution and not the absolute value of the air/fuel ratio, it was decided to use only the simple orsat. Although the error from these calculations is probably rather large, it is reasonable to say the the curves in Figure 9 show a definite trend, and are of some value.

In all calculations, a standard ten inch slide rule was used, and no attempt is made for more than three significant figures; consequently, it is believed that all values given in the tables or represented on the curves are within the possible accuracy of the experimental data.

CONCLUSION

The results of these tests are given in Tables V and VI and are shown in Figures 6 to 13. These curves indicate that if the mixture control remains fixed, the fuel consumption per brake horsepower hour increases with an increase in inlet air temperature. This can be attributed to several factors; an increase in temperature with constant manifold pressure and engine speed results in a richer mixture. Also, increasing the inlet temperature increases the temperatures throughout the cycle and increases the heat loss due to transmission and also increases the dissociation.

The curves on Figure 9 show a definite improvement in mixture distribution with increasing inlet temperature; this is due mostly to the increasing vaporization. It is also noticed that the distribution becomes worse with increasing manifold pressure and better with increasing engine speed. The first can be due to less vaporization at the higher pressures and the latter is due to increased turbulence and the more nearly steady flow conditions in the manifold.

The curves on Figures 12 and 13 show that if the mixture control is varied so as to give the leanest possible mixture with an equal degree of smoothness of operation, the fuel consumption per brake horsepower hour decreases with increasing inlet temperature. This is due to the fact that because of the better distribution the engine can be operated at a leaner mixture at the higher temperature. (See Figures 12 and 13).

The above fact is verified by Carten[1]; however, he is primarily concerned with the effect of the temperature on power output and makes no attempt to show this possibility of a leaner mixture.

From the results of these tests, it seems that the distribution problem should be approached through a better intake manifold design and that no increase in temperature before the carburetor can be justified. The views of Taub[2] and Kegerreis[3] that it is better to heat the fuel than the air seem to be verified.

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1 Carten, L.A., and Coffey, R.T., "A Study of the Effect of Intake Air Temperature on the Performance of a Gasoline Engine", Thesis Department of Mechanical Engineering, M.I.T., 1934 24pp.

2 Taub, Alex, "Mixture Distribution", Journal of the Society of Automotive Engineers, 26: 454-470, April, 1930.

3 Kegerreis, C.S., and Berry, O.C., Temperature Requirements of Hot Spot Manifolds. Purdue University Engineering Experiment Station, Bulletin No. 15. Lafayette, Indiana: Engineering Experiment Station Purdue University, September, 1923 43pp.

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APPENDIX I

FIGURES

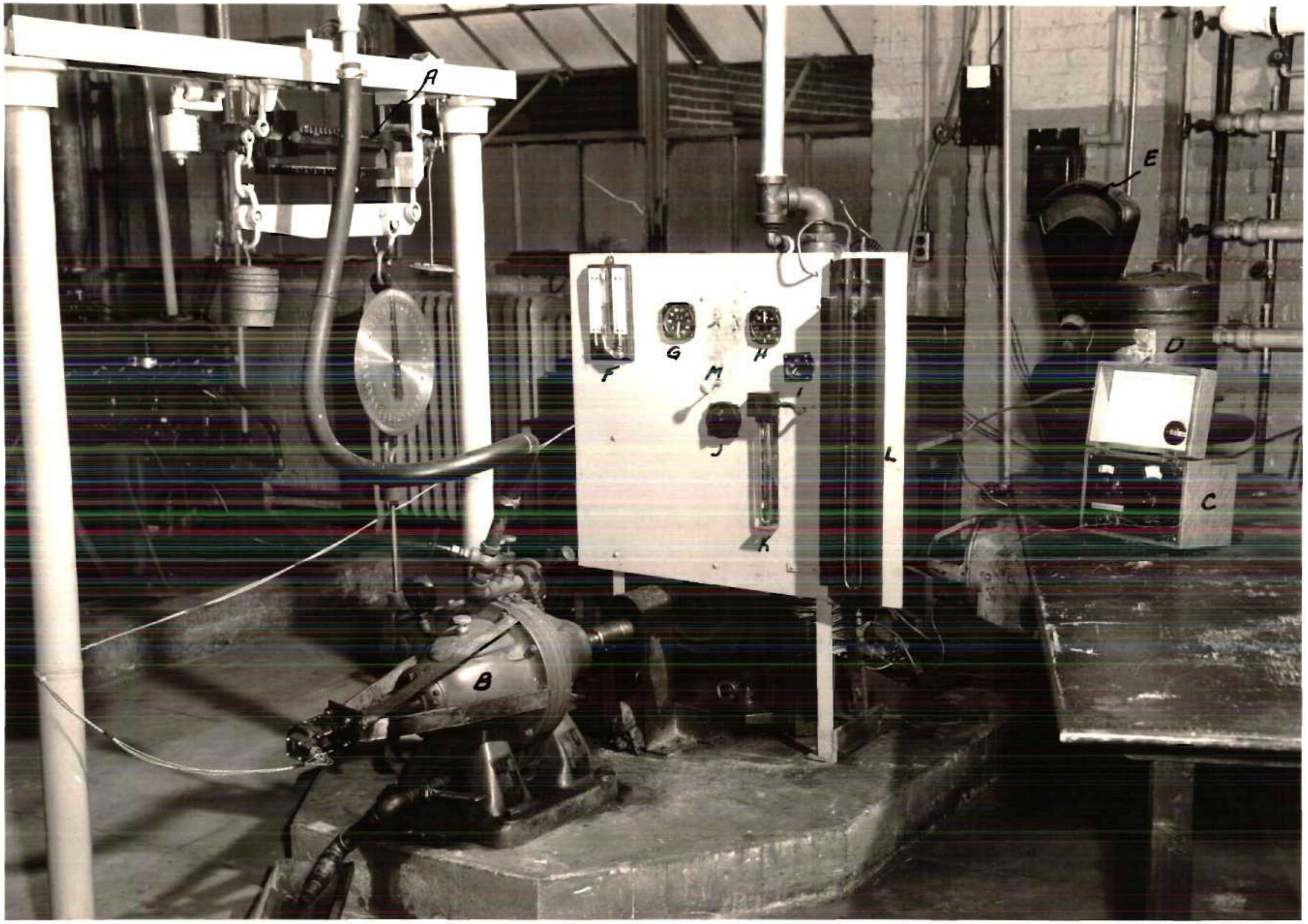


FIGURE 1

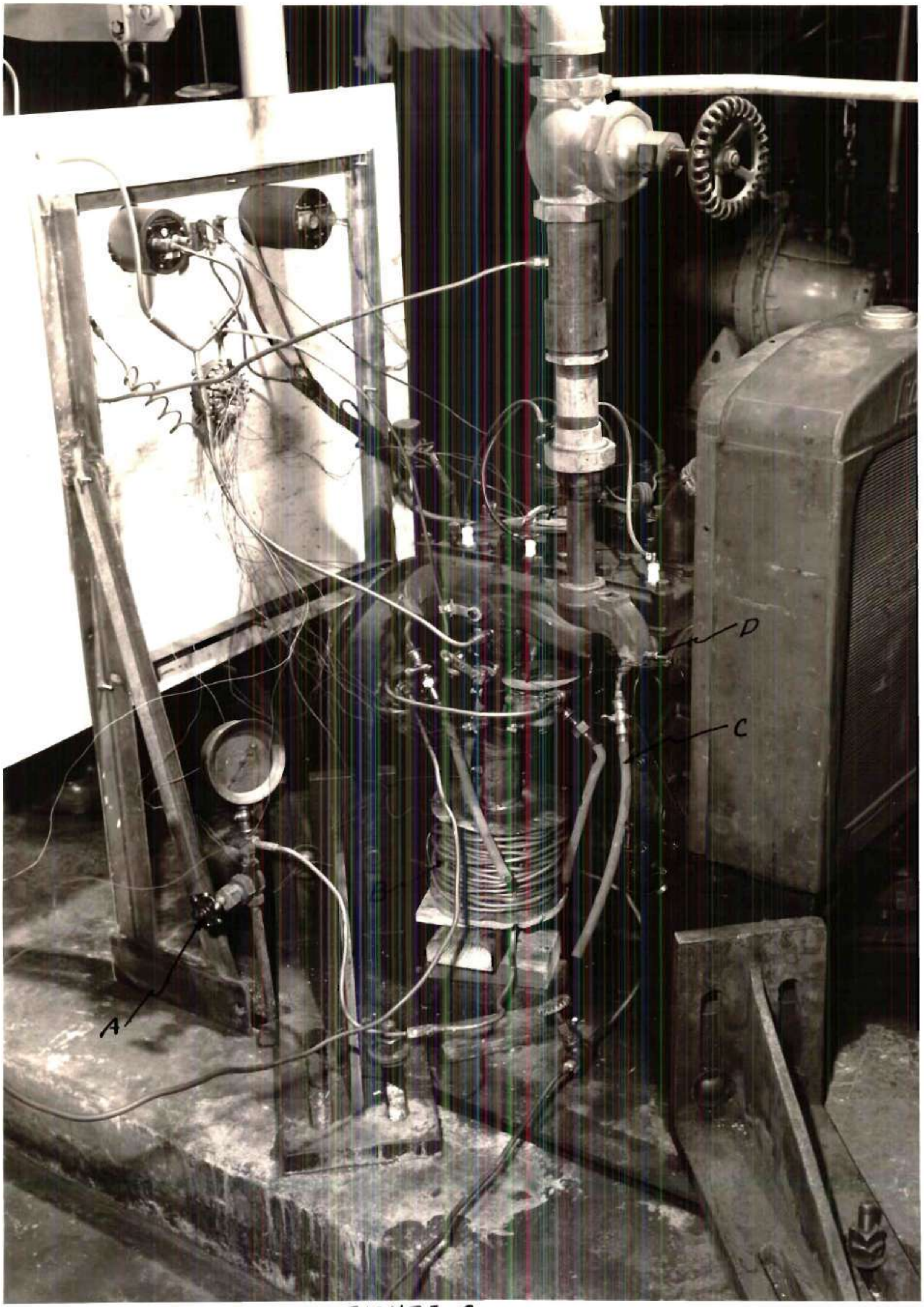


FIGURE 2

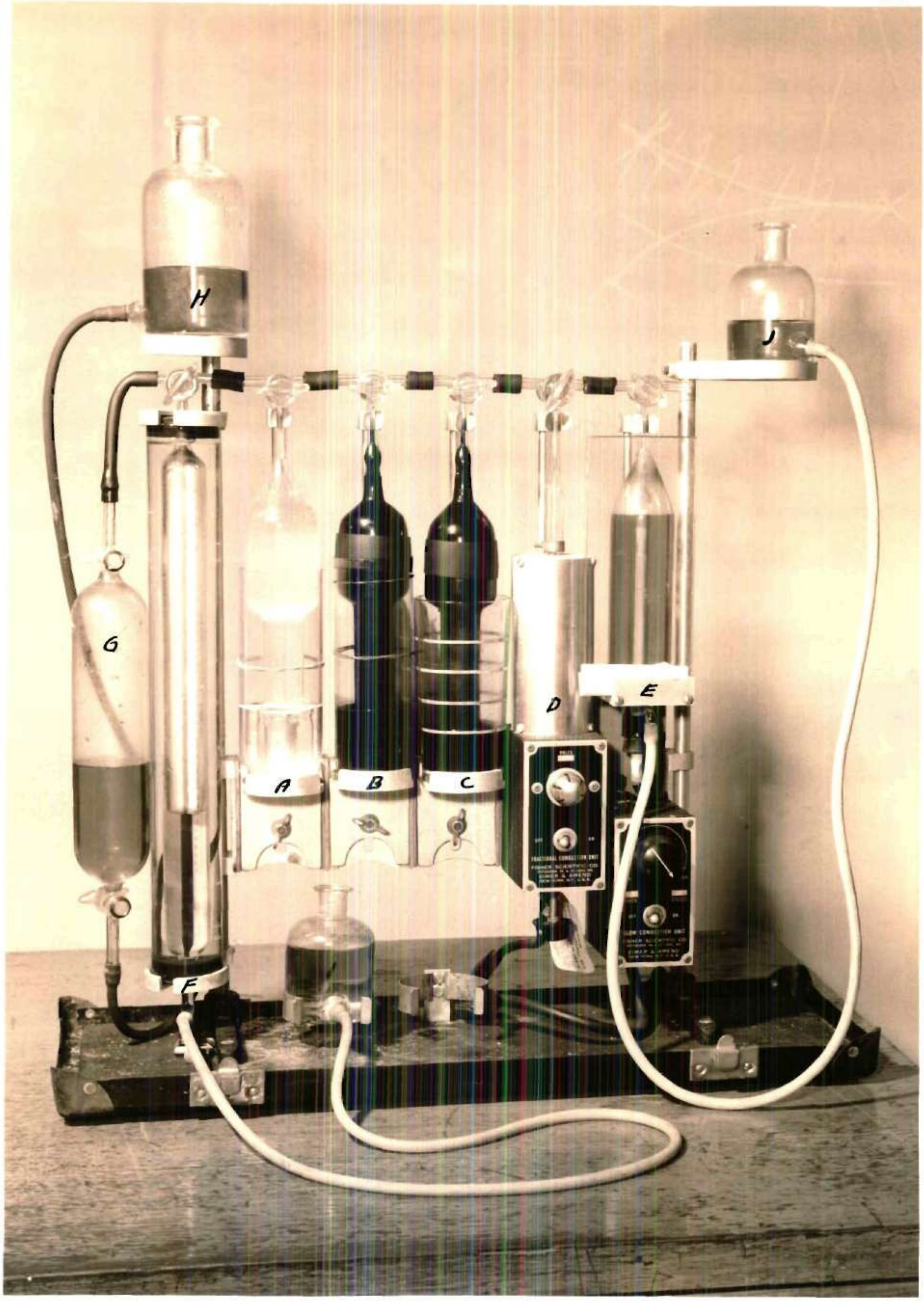
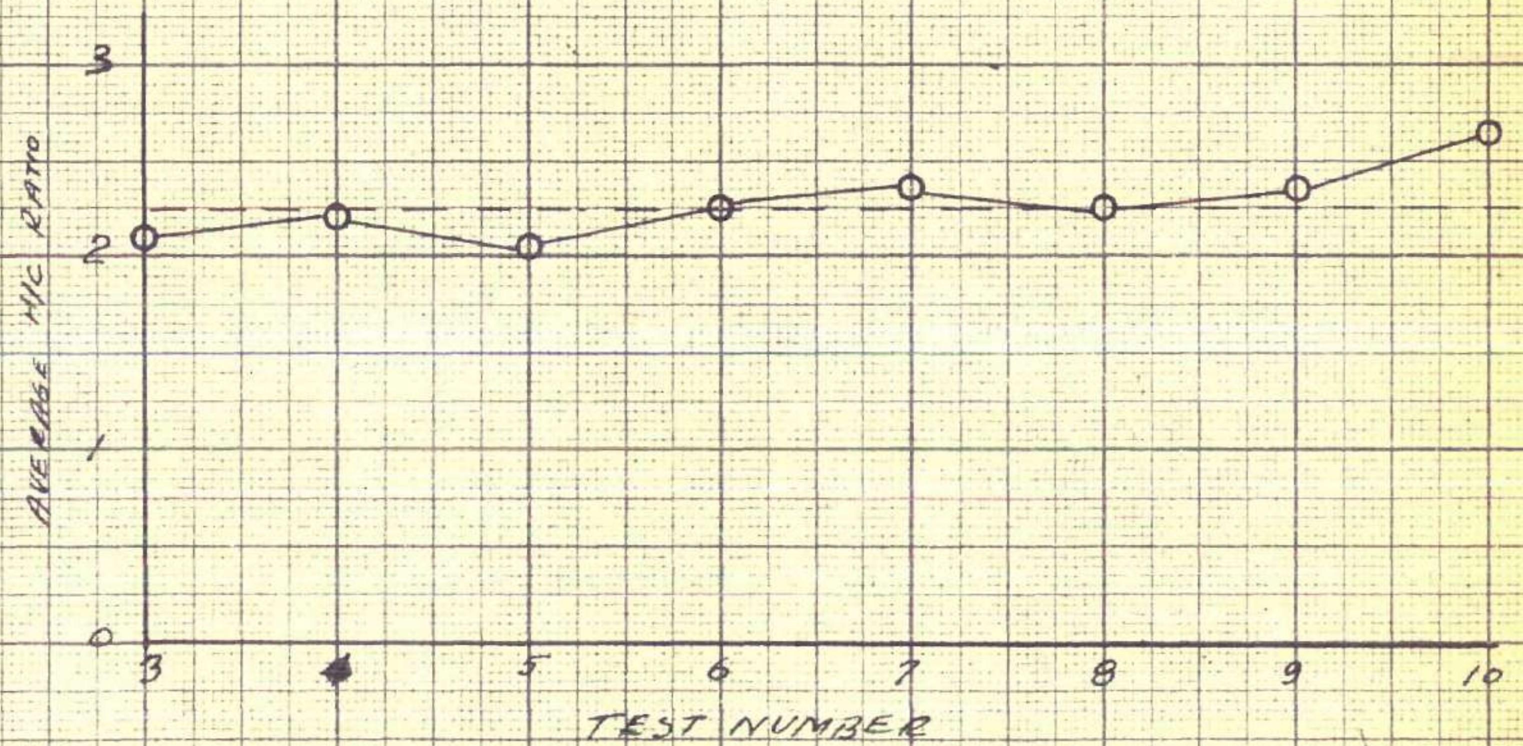


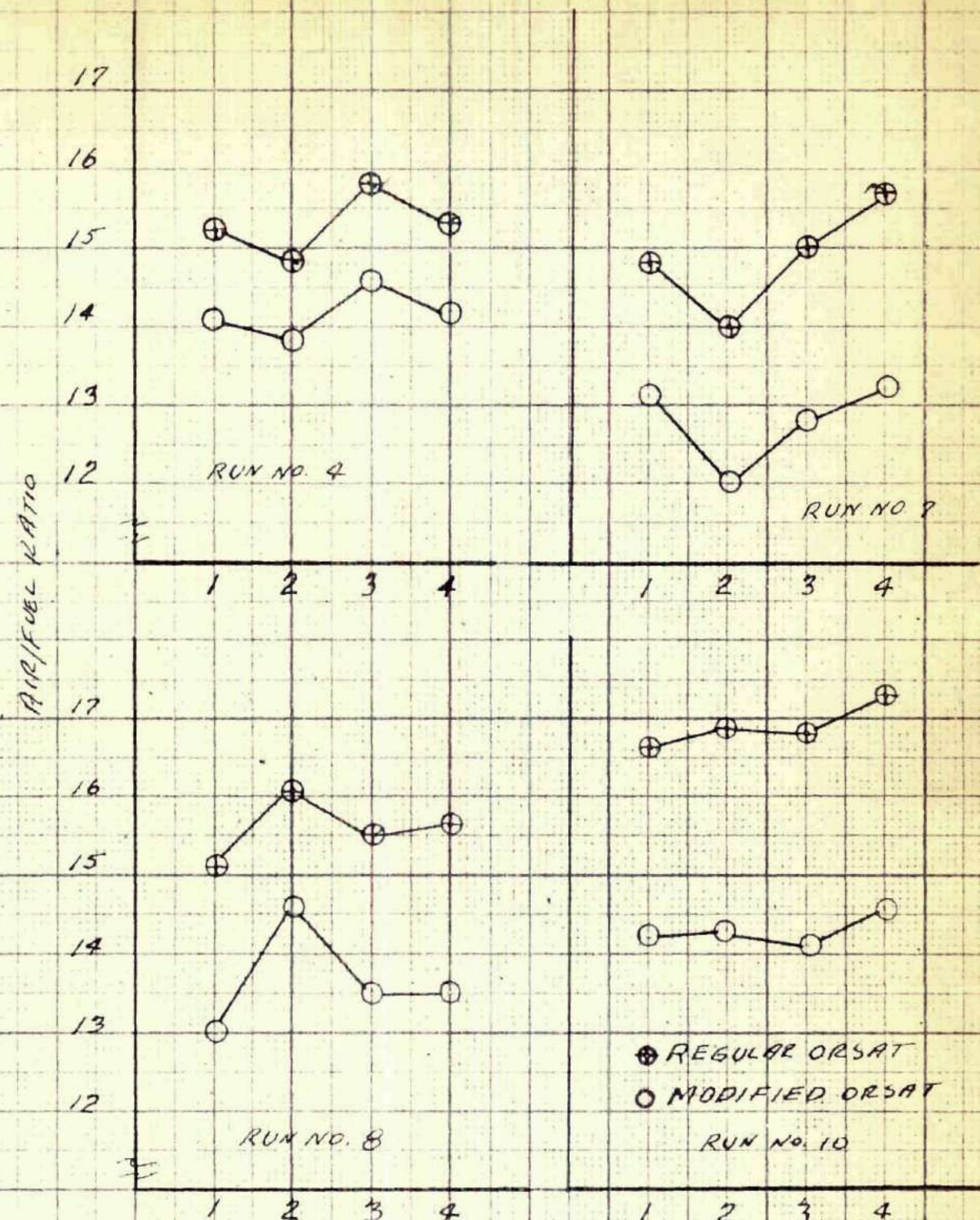
FIGURE 3



VARIATION OF COMPUTED RATIO OF HYDROGEN TO CARBON IN THE FUEL

T. C. BROWN, JR. AUGUST 1950

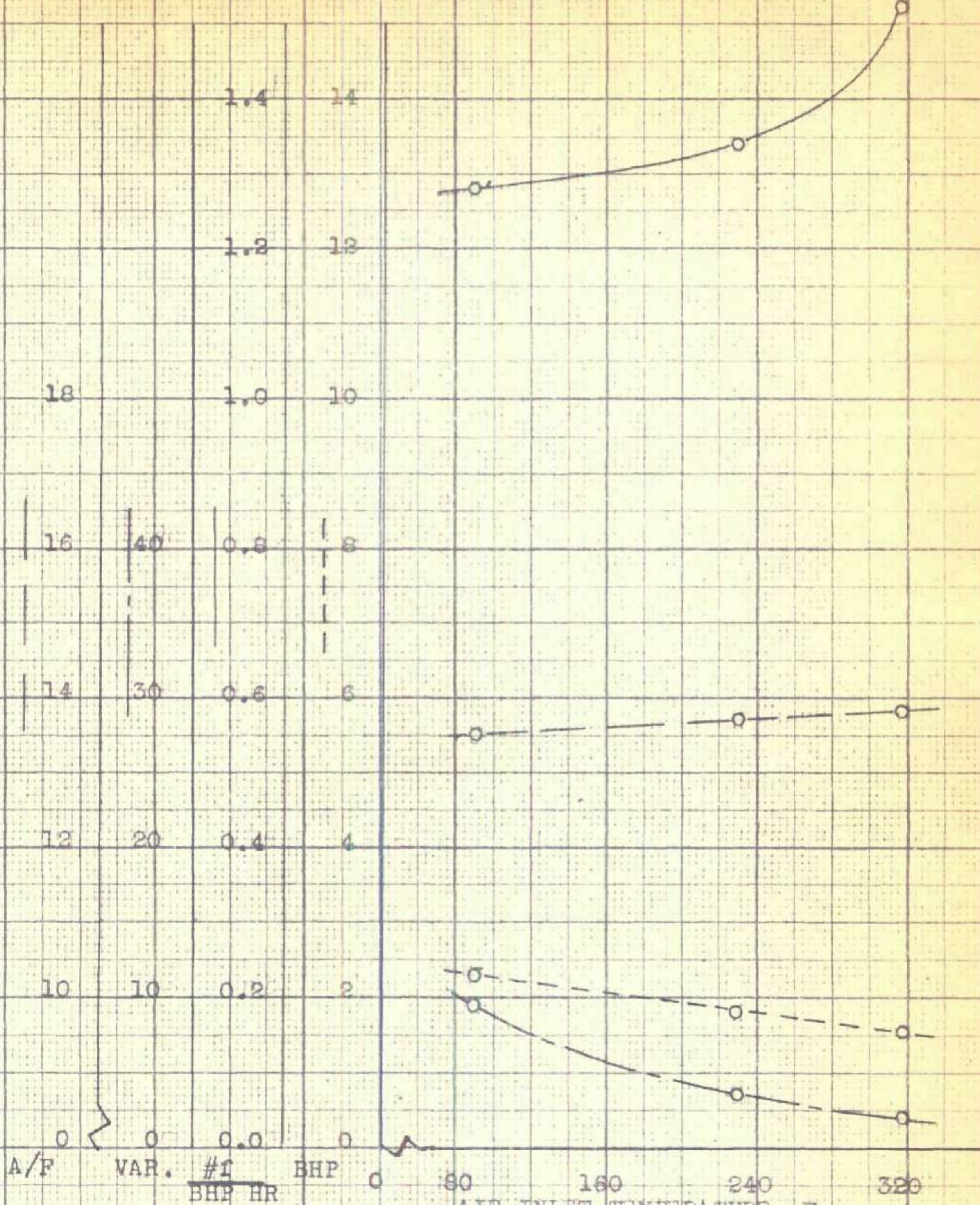
FIGURE 4



CORRELATION OF MIXTURE DISTRIBUTION BY MODIFIED ORSAT TO THAT BY REGULAR ORSAT.

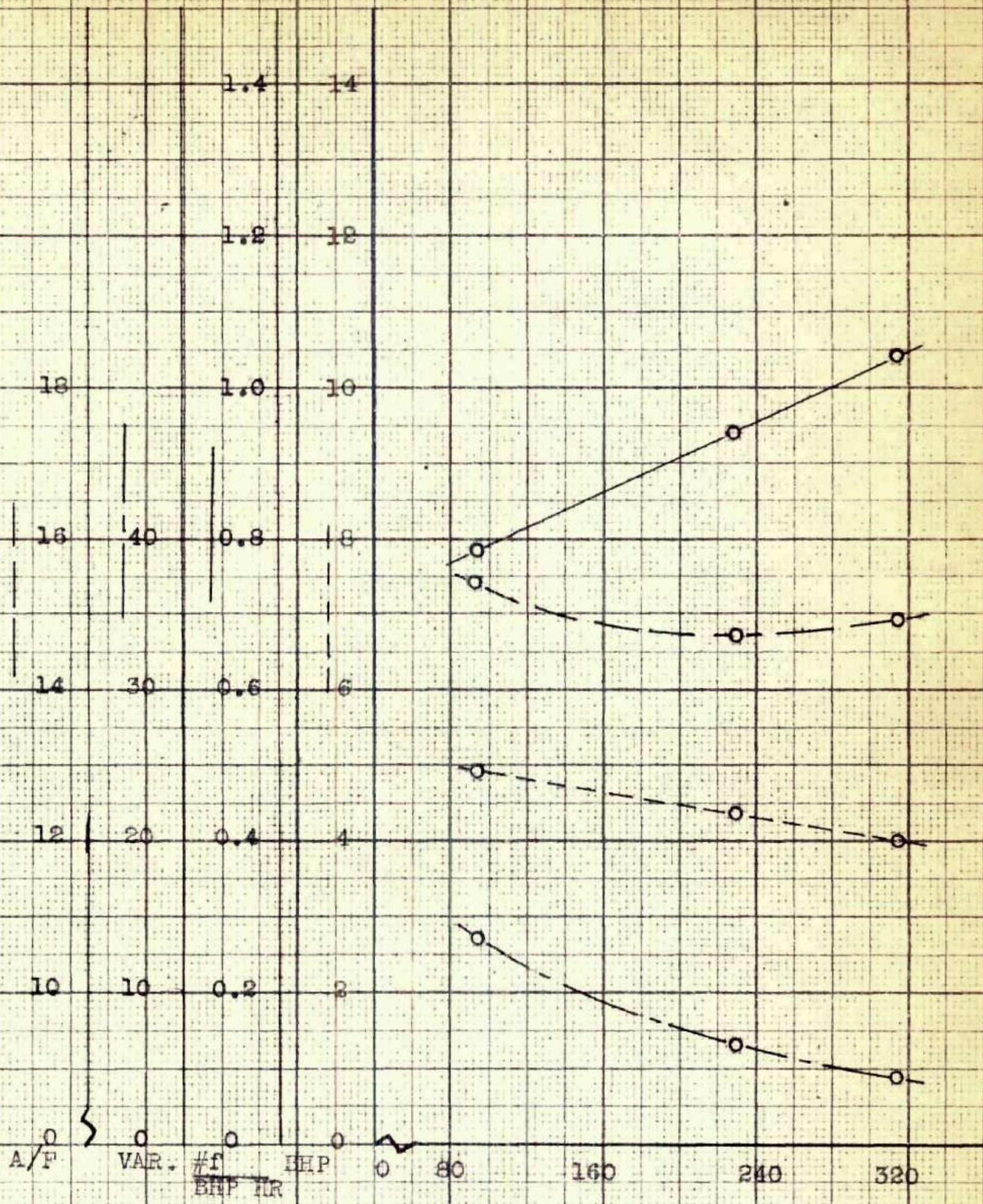
T.C. BROWN, JR. AUGUST 1950

FIGURE 5



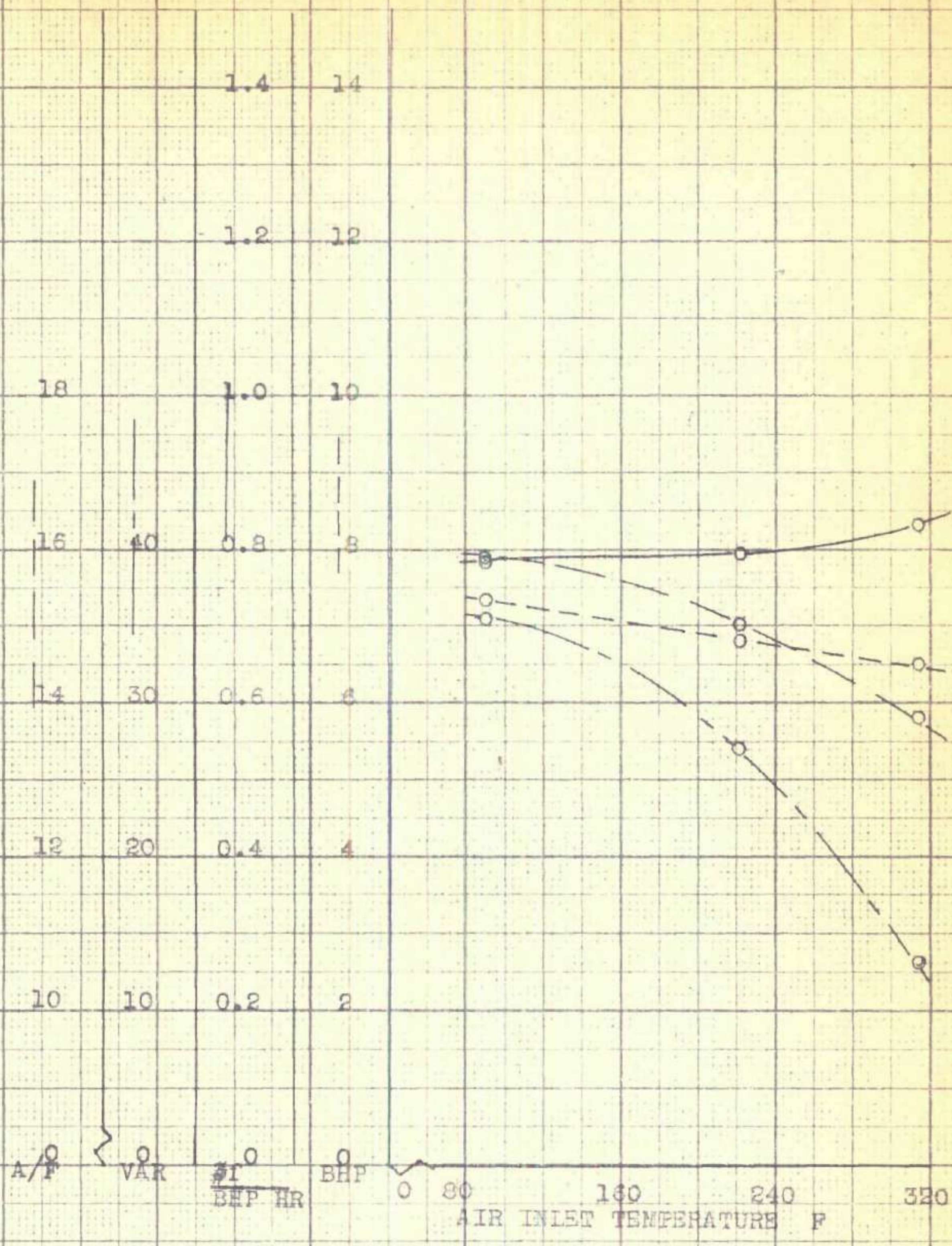
PERFORMANCE OF ENGINE WITH VARYING
AIR INLET TEMP AT 1200 RPM AND
13 INCHES HG. MANIFOLD PRESSURE
CONSTANT JET SETTING
T.C. BROWN JR. SEPT. 1950

FIGURE 6



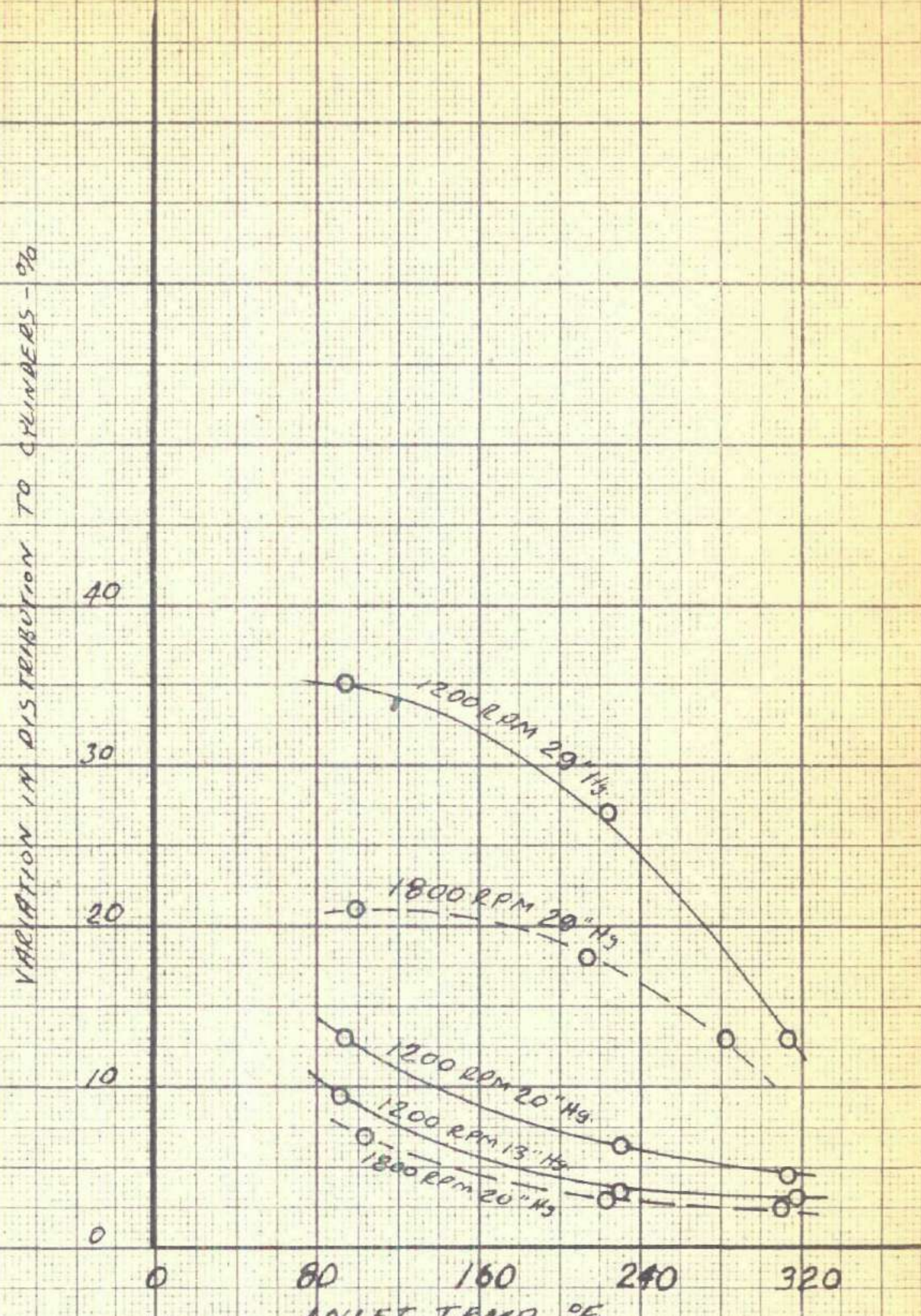
PERFORMANCE WITH VARYING ENGINE AIR INLET TEMP AT 1200 RPM AND 20 INCHES HG. MANIFOLD PRESSURE AND CONSTANT JET SETTING

FIGURE 7



PERFORMANCE OF ENGINE WITH VARYING
AIR INLET TEMP AT 1200 RPM and
29 INCHES HG. MANIFOLD PRESSURE
CONSTANT JET SETTING

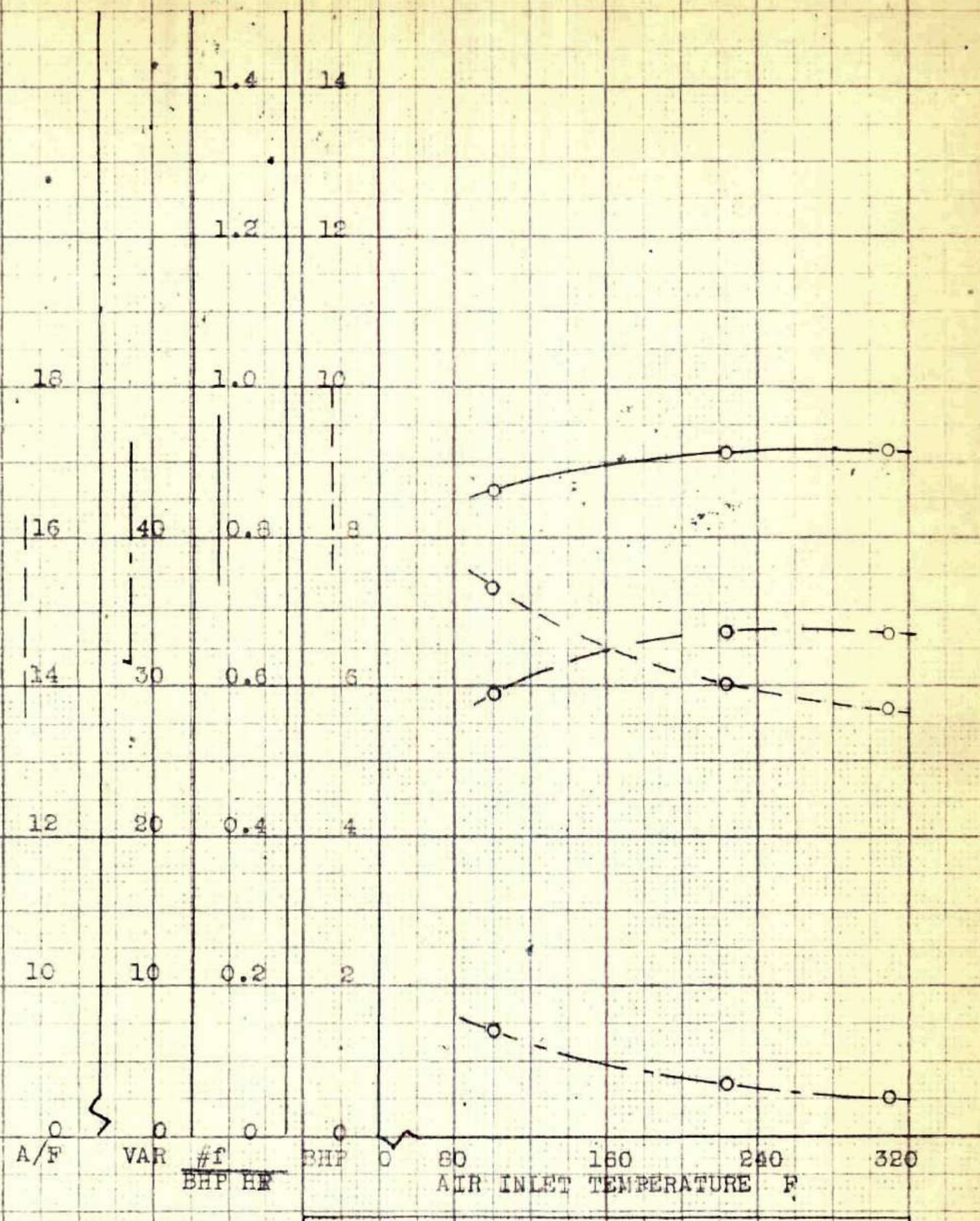
FIGURE 8



% VARIATION VS. INLET TEMP WITH CONSTANT MIXTURE

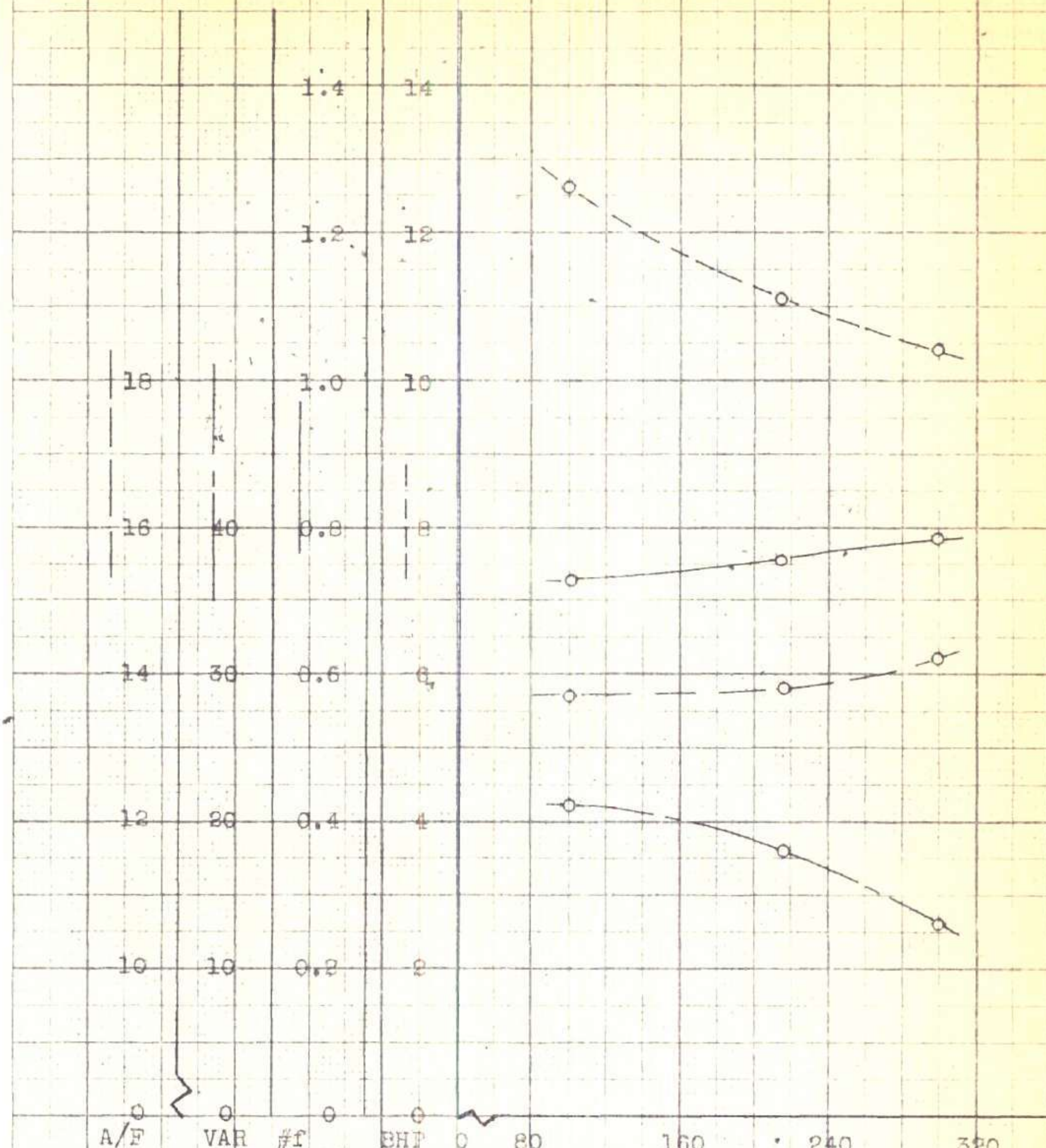
T. C. BROWN, JR. AUGUST 1950

FIGURE 9



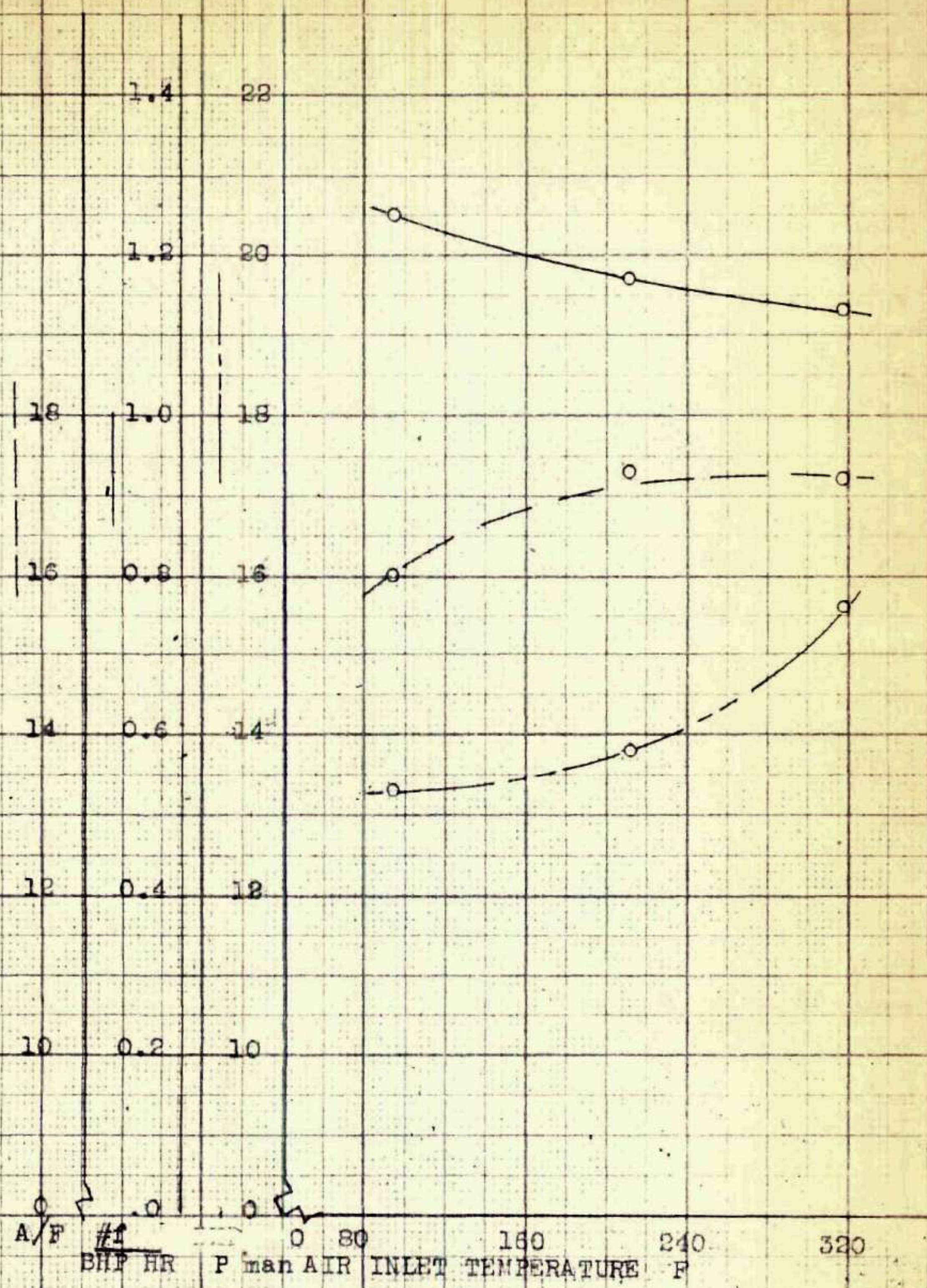
PERFORMANCE OF ENGINE WITH VARYING INLET TEMP AT 1800 RPM AND 20 INCHES HG. MANIFOLD PRESSURE CONSTANT JET SETTING

FIGURE 10



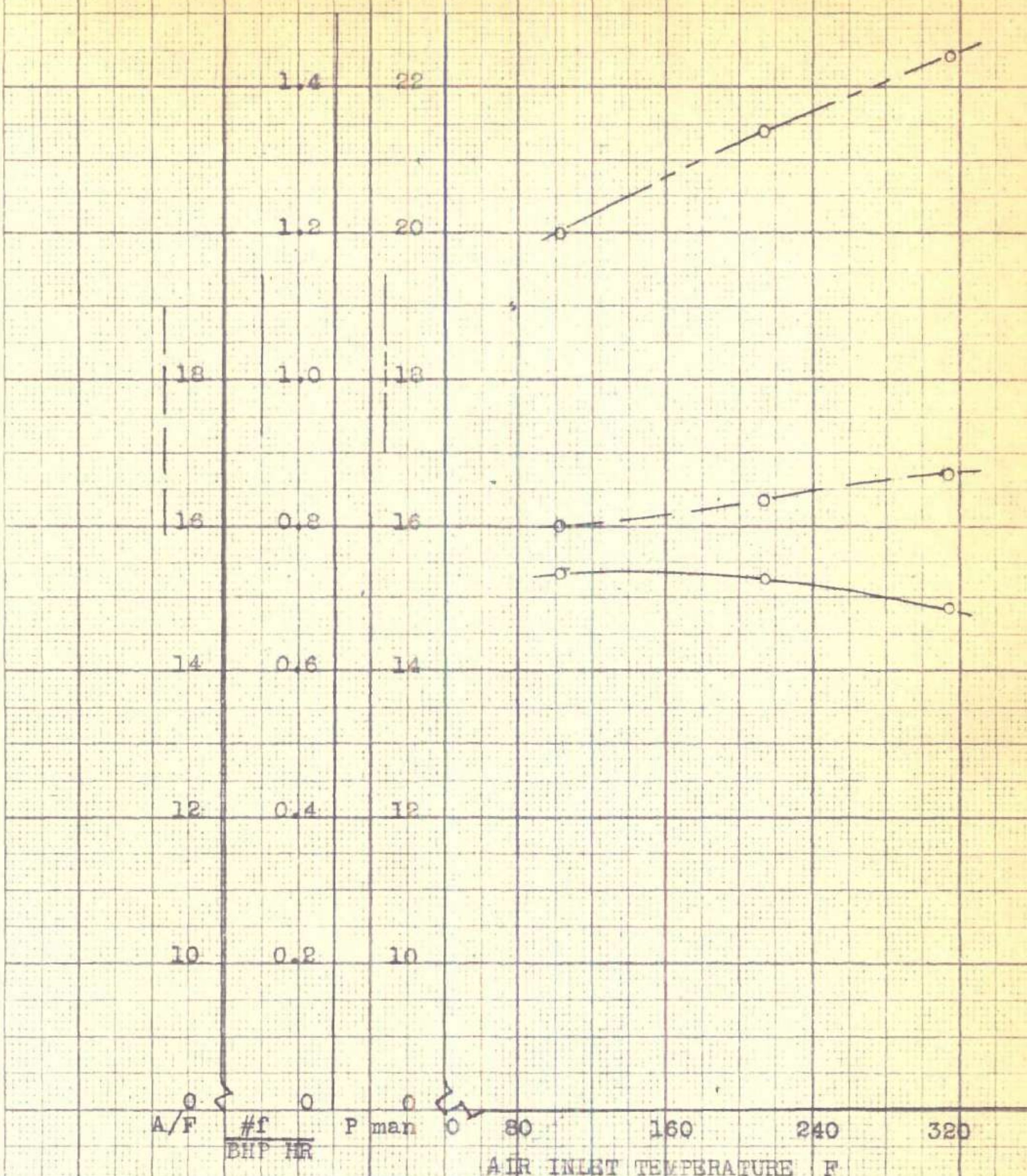
PERFORMANCE OF ENGINE WITH VARYING AIR INLET TEMP AT 1800 RPM AND 29 INCHES HG. MANIFOLD PRESSURE WITH CONSTANT JET SETTING

FIGURE 11



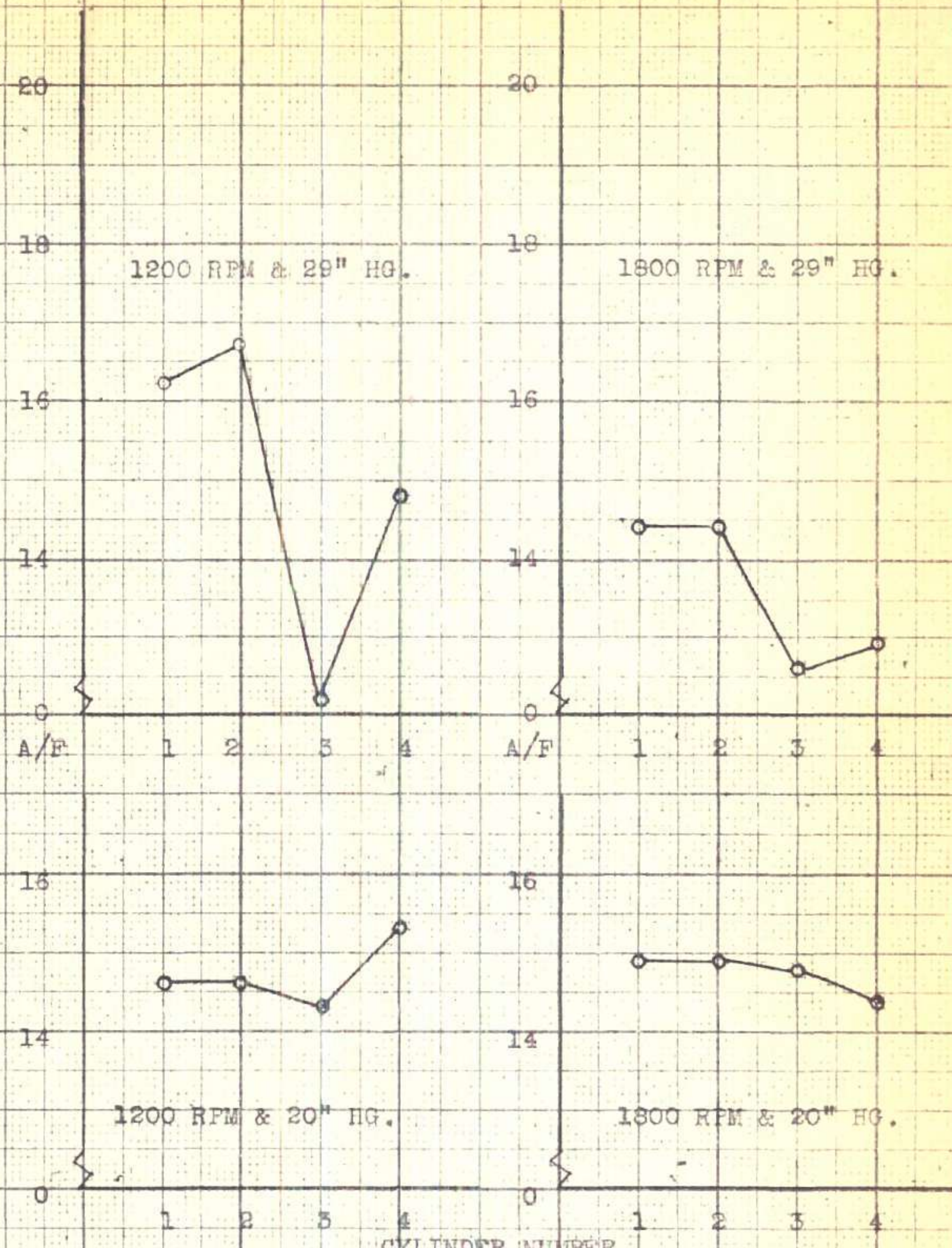
PERFORMANCE OF ENGINE WITH VARYING
AIR INLET TEMP AT 1200 RPM AND 2 BHP
WITH JET VARIED TO GIVE LEANEST
POSSIBLE MIXTURE

FIGURE 12



PERFORMANCE OF ENGINE WITH VARYING INLET AIR TEMP AT 1200 RPM AND 5 BHP WITH JET VARIED TO GIVE LEANEST POSSIBLE MIXTURE

FIGURE 13



TYPICAL DISTRIBUTION BETWEEN VARIOUS CYLINDERS' ALL WITH SAME AIR INLET TEMP.

FIGURE 14

APPENDIX II

TABLES

APPENDIX II

TABLE I Observed Data Group A

Test No.	3	4	5	6	7
P bar.	29.1	29.2	29.2	29.1	29.1
T db	89	95	95	95	103
T wb	80	77	79	79	79
W	5.25	4.6	4.3	3.6	20.1
N	1200	1200	1200	1200	1200
P man.	12.9	12.8	12.7	13.0	20.0
t	515	378	634	980	655
w	0.42	0.38	0.44	0.75	0.79
T1	156	185	192	202	163
T2	156	185	190	200	160
T3	155	193	201	213	151
T4	170	197	203	212	165
T5	853	805	767	781	847
T6	819	757	761	781	839
T7	835	797	767	797	833
T8	820	807	755	767	824
T9	95	221	268	304	105
T10	138	135	139	136	156
Orsat results for cylinder No.1					
CO_2	11.8	13.6	11.2	11.9	11.4
O_2	3.1	1.0	0.9	2.7	1.0
CO	0.7	0.9	4.7	1.2	3.5
H_2	0.0	0.1	1.0	0.7	0.1
Contr.	1.3	1.4	3.1	1.9	3.9
CO_2'	1.4	0.8	1.5	0.8	1.4
Orsat results for cylinder No.2					
CO_2	13.9	14.0	12.1	12.4	12.0
O_2	1.5	0.8	0.9	2.5	0.9
CO	0.4	0.8	3.4	0.8	3.9
H_2	0.0	0.2	0.4	0.4	0.5
Contr.	1.1	1.3	3.2	2.0	3.3
CO_2'	1.1	0.8	2.0	1.2	1.7
Orsat results for cylinder No.3					
CO_2	13.2	13.0	11.6	12.1	10.3
O_2	2.0	1.7	1.3	2.9	0.7
CO	0.7	0.9	3.6	1.0	4.4
H_2	0.1	0.3	0.5	0.4	0.4
Contr.	0.8	1.2	5.8	2.1	5.2
CO_2'	0.7	0.9	1.8	1.3	7.1
Orsat results for cylinder No.4					
CO_2	13.7	12.9	10.9	11.5	9.4
O_2	0.9	1.3	0.7	1.9	2.3
CO	0.5	1.4	5.4	2.5	4.5
H_2	0.4	0.4	0.8	0.5	0.7
Contr.	1.4	1.2	4.7	3.3	5.3
CO_2'	0.8	0.9	1.3	1.4	7.0

TABLE I Observed Data Group A (continued)

Test No.	8	9	10	11
P bar.	29.0	29.0	29.0	29.0
T db	97	96	95	103
T wb	80	79	79	81
W	17.8	18.0	17.9	30.0
N	1200	1200	1200	1200
P man.	19.8	19.9	20.1	28.9
t	989	600	560	656
w	0.84	0.61	0.56	0.90
T1	192	205	216	243
T2	198	203	217	246
T3	196	207	223	248
T4	200	210	221	243
T5	842	842	838	917
T6	796	857	867	922
T7	839	859	862	899
T8	841	875	868	886
T9	228	257	289	315
T10	151	149	149	162
Orsat results for cylinder No.1				
CO_2	10.8	10.9	11.1	12.9
O_2	2.3	2.9	1.8	0.9
CO	3.7	2.8	2.1	1.7
H_2	0.6	0.3	0.6	0.8
Contr.	4.5	1.2	4.1	1.2
$CO_{\frac{1}{2}}$	1.5	1.1	1.8	0.2
Orsat results for cylinder No.2				
CO_2	11.3	11.7	11.3	12.7
O_2	1.7	2.1	1.9	0.8
CO	2.5	1.8	1.8	1.7
H_2	0.5	0.4	0.5	0.4
Contr.	3.7	3.1	4.0	3.9
$CO_{\frac{1}{2}}$	0.5	1.4	1.8	0.3
Orsat results for cylinder No.3				
CO_2	10.8	10.9	10.8	10.4
O_2	2.1	2.4	2.3	0.9
CO	3.3	2.4	2.4	5.0
H_2	0.7	0.7	0.6	0.8
Contr.	4.2	3.4	4.3	4.3
$CO_{\frac{1}{2}}$	1.6	1.5	1.8	1.4
Orsat results for cylinder No.4				
CO_2	9.2	9.9	9.7	10.9
O_2	2.7	3.6	3.1	2.2
CO	4.8	2.7	3.1	2.8
H_2	0.8	0.4	0.7	0.6
Contr.	5.3	3.3	4.9	1.2
$CO_{\frac{1}{2}}$	1.5	1.3	1.9	1.8

TABLE II Observed Data Group B

Test No.	12	13	14	15	16
P bar.	29.2	28.9	28.9	29.2	29.2
T db	88	100	100	94	99
T wb	69	80	80	73	75
W	11.6	9.4	7.8	24.5	21.7
N	1200	1200	1200	1200	1200
P man.	13.0	12.8	12.6	19.9	20.1
t	906	528	758	794	795
w	0.74	0.37	0.50	0.85	0.90
T1	147	187	209	156	196
T2	145	187	207	154	196
T3	145	194	217	145	199
T4	161	194	214	163	201
T5	729	749	729	864	825
T6	731	734	722	876	834
T7	730	710	697	872	847
T8	742	763	732	878	849
T9	91	230	318	93	230
T10	135	140	142	151	152
	Orsat results for cylinder No.1				
CO_2	10.1	9.3	9.1	12.0	10.2
O_2	1.1	1.1	0.9	1.5	1.7
CO	5.4	6.5	6.5	1.1	4.6
	Orsat results for cylinder No.2				
CO_2	10.4	9.9	9.6	11.6	10.9
O_2	0.8	0.7	0.7	2.5	1.4
CO	5.1	5.9	6.1	1.9	3.9
	Orsat results for cylinder No.3				
CO_2	9.5	9.0	9.0	11.4	10.4
O_2	1.5	1.9	1.3	1.5	1.7
CO	6.1	6.3	6.4	3.3	4.6
	Orsat results for cylinder No.4				
CO_2	9.1	8.8	8.8	11.1	9.3
O_2	0.5	1.3	1.2	1.2	3.0
CO	7.8	7.0	6.9	3.9	4.7

TABLE II Observed Data Group B (continued)

Test No.	17	18	19	20	21
P bar.	29.1	29.2	29.1	29.1	29.1
T db	100	91	105	103	94
T wb	75	73	77	73	74
W	20.0	36.7	34.2	33.2	5.5
N	1200	1200	1200	1200	1800
P man.	19.8	29.1	29.0	29.0	12.9
t	885	665	664	679	534
w	1.02	1.06	1.00	1.05	0.62
T1	218	142	203	237	142
T2	218	142	203	237	142
T3	225	131	194	239	140
T4	223	151	203	156	188
T5	830	889	893	883	881
T6	837	856	843	853	884
T7	842	841	822	850	882
T8	847	893	832	866	937
T9	315	91	223	315	93
T10	152	149	158	162	144
Orsat results for cylinder No.1					
CO_2	10.1	9.5	12.2	11.4	11.1
O_2	2.1	5.6	1.9	0.6	0.8
CO	4.1	1.5	1.3	3.5	4.9
Orsat results for cylinder No.2					
CO_2	10.5	10.3	11.7	11.0	11.0
O_2	1.3	4.3	2.1	0.6	0.7
CO	4.0	1.5	1.4	4.4	4.8
Orsat results for cylinder No.3					
CO_2	10.0	6.4	6.7	8.1	10.0
O_2	1.8	2.4	1.3	0.9	1.0
CO	4.5	10.2	10.5	8.6	5.9
Orsat results for cylinder No.4					
CO_2	9.9	9.0	7.8	8.9	9.6
O_2	1.5	1.9	1.3	1.1	0.8
CO	5.2	6.5	6.5	6.7	6.6

TABLE II Observed Data Group B (continued)

Test No.	22	23	24	25	26
P bar.	29.1	29.1	29.1	29.1	29.1
T db	96	101	104	103	102
T wb	77	79	81	79	81
W	3.8	19.0	20.0	24.3	42.0
N	1800	1800	1800	1800	1800
P man.	12.9	20.2	20.0	20.0	29.0
t	582	408	435	321	260
w	0.67	0.59	0.66	0.56	0.66
T1	180	221	194	149	151
T2	130	221	190	149	151
T3	181	228	194	145	140
T4	188	225	198	150	156
T5	825	976	983	1026	1090
T6	828	980	987	1018	1043
T7	837	1007	1013	1047	1030
T8	924	1042	1047	1072	1047
T9	225	311	225	100	99
T10	144	153	154	156	162
Orsat results for cylinder No.1					
CO_2	9.0	12.2	12.3	11.6	12.5
O_2	2.4	0.5	0.5	0.3	1.1
CO	5.6	2.7	2.4	4.1	2.0
Orsat results for cylinder No.2					
CO_2	9.5	12.1	12.0	11.3	13.1
O_2	1.7	0.6	0.6	0.4	1.2
CO	5.8	2.6	2.7	4.4	1.1
Orsat results for cylinder No.3					
CO_2	9.2	11.7	11.8	10.8	8.2
O_2	1.6	0.7	0.8	0.7	0.4
CO	6.3	3.0	2.9	4.5	9.3
Orsat results for cylinder No.4					
CO_2	8.9	11.8	12.1	11.0	8.4
O_2	2.2	0.5	0.4	0.4	0.5
CO	6.3	3.2	3.0	5.2	8.8

TABLE II Observed Data Group B (continued)

Test No.	27	28
P Bar.	29.1	29.1
T db	101	105
T wb	82	81
W	37	34.8
N	1800	1800
P man.	28.8	29.0
t	636	255
w	1.48	0.58
T1	196	228
T2	198	228
T3	192	228
T4	199	226
T5	1054	1057
T6	1012	1014
T7	990	1018
T8	1024	1043
T9	214	302
T10	160	160
Orsat results for cylinder No.1		
CO_2	12.5	12.5
O_2	0.5	0.5
CO	2.7	2.2
Orsat results for cylinder No.2		
CO_2	12.1	12.6
O_2	0.5	0.6
CO	3.0	2.0
Orsat results for cylinder No.3		
CO_2	8.9	9.5
O_2	0.4	0.6
CO	8.1	7.0
Orsat results for cylinder No.4		
CO_2	10.1	10.7
O_2	0.3	0.5
CO	6.5	4.8

TABLE III Observed Data Group C

Test No.	29	30	31	32	33	34
P bar.	29.1	29.1	29.1	29.1	29.1	29.1
T db	96	104	99	103	109	112
T wb	79	81	79	80	81	83
W	10.0	10	10	25	25	25
N	1200	1200	1200	1200	1200	1200
P man.	13.3	13.8	15.6	20.0	21.4	22.4
t	837	863	573	787	547	590
w	0.58	0.56	0.36	0.80	0.55	0.56
T1	156	187	217	163	200	238
T2	156	187	217	163	200	238
T3	156	194	230	156	198	246
T4	170	199	225	173	201	243
T5	788	765	777	847	859	878
T6	748	756	773	833	846	863
T7	772	785	796	864	891	923
T8	847	843	857	892	914	925
T9	95	212	318	102	214	315
T10	142	149	149	158	156	160
CO_2 avg.	11.8	10.4	11.4	11.5	10.8	11.3
O_2 avg.	1.4	4.2	3.3	2.1	2.3	2.9
CO avg.	1.9	2.0	1.2	2.1	2.5	1.7

TABLE IV Calculated Data Group A

Test No.	3	4	5	6	7
BHP	1.05	0.92	0.86	0.72	4.02
#f/Hr	3.64	3.62	2.50	2.75	4.34
#f/BHP-Hr	3.47	3.94	2.91	3.83	1.08
CH_4 1	0.0	0.54	1.5	0.8	1.4
C_2H_6 1	1.0	0.13	0.0	0.0	0.0
C - 1	14.5	15.3	17.4	13.9	16.3
H 1	33.5	31.8	35.8	31.5	36.9
H/C 1	2.31	2.08	2.06	2.27	2.27
A/F* 1	14.8	14.1	12.0	15.4	13.1
CH_4 2	0.0	0.4	0.9	0.7	0.4
C_2H_6 2	0.7	0.2	0.5	0.3	0.7
C 2	15.7	15.6	17.5	14.4	17.6
H 2	30.5	31.2	35.7	32.0	33.7
H/C 2	1.94	2.00	2.04	2.22	1.92
A/F* 2	13.7	13.8	12.0	14.9	12.0
CH_4 3	0.0	0.1	1.8	0.7	2.0
C_2H_6 3	0.4	0.4	0.0	0.3	0.0
C 3	14.7	14.8	17.0	13.4	16.7
H 3	29.2	32.0	35.6	30.9	43.2
H/C 3	1.98	2.16	2.09	2.31	2.59
A/F* 3	14.7	14.6	12.3	15.9	12.7
CH_4 4	0.54	0.1	1.8	1 4	2.0
C_2H_6 4	0.13	0.4	0.0	0.0	0.0
C 4	15.1	15.2	17.6	15.4	15.9
H 4	33.3	32.6	35.5	35.2	39.6
H/C 4	2.20	2.14	2.01	2.29	2.49
A/F* 4	14.3	14.2	11.9	13.3	13.2
Avg. H/C	2.11	2.19	2.05	2.27	2.35
A/F 1	17.6	15.2	13.6	16.6	14.8
A/F 2	15.2	14.8	13.8	16.5	14.0
A/F 3	16.6	15.8	14.2	16.7	15.0
A/F 4	15.4	15.3	13.1	15.6	15.7

TABLE IV Calculated Data Group A (continued)

Test No	8	9	10	11
BHP	3.56	3.60	3.59	6.00
#f/Hr	3.06	3.66	3.60	4.94
#f/BHP-Hr	1.19	1.02	1.01	0.82
CH_4 1	1.5	0.4	1.8	0.3
C_2H_6 1	0.0	0.3	0.0	0.0
C 1	16.0	14.7	15.0	14.9
H 1	33.6	30.7	40.2	28.7
H/C 1	2.10	2.09	2.67	1.93
A/F* 1	13.1	14.5	14.2	14.5
CH_4 2	0.5	1.4	1.8	0.8
C_2H_6 2	0.0	0.0	0.0	0.0
C 2	14.3	14.9	14.9	15.2
H 2	34.7	35.3	40.0	31.3
H/C 2	2.43	2.37	2.68	2.06
A/F* 2	13.9	14.3	14.3	14.2
CH_4 3	1.6	1.5	1.8	1.4
C_2H_6 3	0.0	0.0	0.0	0.0
C 3	15.7	14.8	15.0	16.8
H 3	34.9	36.6	38.3	38.5
H/C 3	2.23	2.47	2.55	2.29
A/F* 3	13.5	14.3	14.1	12.5
CH_4 4	1.5	1.3	1.9	0.0
C_2H_6 4	0.0	0.0	0.0	1.6
C 4	15.5	13.9	14.7	16.9
H 4	36.4	33.8	39.1	39.5
H/C 4	2.35	2.43	2.66	2.34
A/F*4	13.5	15.2	14.5	12.5
Avg. H/C	2.25	2.34	2.64	2.15
A/F 1	15.1	15.9	16.6	15.6
A/F 2	16.1	16.3	16.9	15.3
A/F 3	15.5	16.7	16.8	14.5
A/F 4	15.6	17.5	17.3	16.3

TABLE V Calculated Data Group B

Test No.	12	13	14	15
BHP	2.30	1.88	1.56	4.90
#f/Hr	2.94	2.52	2.37	3.86
#f/BHP-Hr	1.28	1.34	1.52	0.787
Var.	9.4	3.6	2.1	13.3
Avg. A/F	13.5	13.7	13.8	15.4
A/F 1	13.9	13.6	13.8	16.6
A/F 2	13.9	13.6	13.8	16.0
A/F 3	13.9	14.0	14.0	14.7
A/F 4	12.6	13.5	13.7	14.4

TABLE V Calculated Data Group B

Test No.	16	17	18	19	20	21	22
BHP	4.34	4.00	7.32	6.82	6.64	1.65	1.14
#f/Hr	4.17	4.15	5.74	5.43	5.50	4.18	4.15
#f/BHP-Hr	0.938	1.04	0.785	0.796	0.828	2.54	3.64
A/F 1	14.6	15.2	19.5	16.2	14.6	13.4	14.7
A/F 2	14.6	15.0	18.3	16.7	14.1	13.6	14.0
A/F 3	14.3	14.9	12.6	12.2	12.7	13.5	13.8
A/F 4	15.3	14.3	13.2	14.8	13.8	13.4	14.0
Var.	6.5	4.7	35.3	26.9	13.0	1.5	6.1
Avg. A/F	14.7	14.9	15.9	15.0	13.8	13.5	14.1

TABLE V Calculated Data Group B (continued)

Test No.	23	24	25	26	27	28
BHP	5.70	6.00	7.29	12.6	11.1	10.4
#f/Hr	5.21	5.46	6.28	9.14	8.38	8.18
#f/BHP-Hr	0.915	0.910	0.860	0.725	0.755	0.783
A/F 1	14.7	14.9	13.8	15.0	15.3	14.9
A/F 2	14.9	14.9	13.8	15.4	14.4	15.0
A/F 3	14.8	14.8	14.2	12.1	12.6	13.0
A/F 4	14.5	14.4	13.2	12.4	12.9	14.0
Var.	2.7	3.3	6.9	21.0	18.0	13.0
Avg. A.F	14.7	14.7	13.9	13.7	13.8	14.2

TABLE VI Calculated Data Group C

Test No.	29	30	31	32	33	34
BHp	2.0	2.0	2.0	5.0	5.0	5.0
#f/Hr	2.49	2.34	2.26	3.66	3.62	3.42
#f/BHP-Hr	1.25	1.17	1.13	0.732	0.725	0.684
Avg. A/F	16.0	17.3	17.2	16.0	16.35	16.7

APPENDIX III

SAMPLE CALCULATIONS

APPENDIX III

SAMPLE CALCULATIONS

A. Brake Horsepower - BHP

From the general equation

$$BHP = \frac{2\Pi WLN}{3300}$$

L is designed by the manufacturer so that

$$BHP = \frac{WN}{6000}$$

B. Pounds of fuel per hour - #f/Hr.

$$\#f/Hr. = \frac{3600w}{t}$$

C. Pounds of fuel per brake horsepower-hour-#f/BHP-Hr.

$$\#f/BHP\text{-}Hr = \frac{\#f/Hr}{BHP}$$

D. Ethane - C_2H_6

$$C_2H_6 = 2/3(CO_2^1 - Contr.)^1$$

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1 Matuszak, M.P., Gas-Analysis Manual. New York: Fisher Scientific Co., 1949 64pp.

E. Methane - CH_4

$$CH_4 = CO\tfrac{1}{2} - 2C_2H_6$$ [1]

F. Number of carbon atoms in exhaust gas - C

Assuming that the combustion is expressed by:

$$C_xH_y + O_2 + 3.77N_2 = CO_2 + CO + O_2 + H_2 + CH_4 + C_2H_6 + H_2O$$

$$C = x = CO_2 + CO + CH_4 + 2C_2H_6$$

G. Number of Hydrogen atoms in the exhaust gas - H

From the same assumption as made in F.:

$$H = y = 2H_2 + 4CH_4 + 6C_2H_6 + 2H_2O$$

However, since the analysis is on the dry basis, the water must be calculated from an oxygen balance.

Assuming:

$$N_2 = 100 - (CO_2 + CO + O_2 + H_2 + CH_4 + C_2H_6)$$

This gives:

$$H = y = 2H_2 + 4CH_4 + 6C_2H_6 + \frac{4N_2}{3.77} - (4CO_2 + 2CO + 4O_2)$$

H. Air/Fuel ratio by modified orsat - A/F*

Assuming that all of the Nitrogen is the exhaust gas comes from the air that is supplied to the engine, and assuming that all of the carbon in the exhaust gas comes from the fuel.

$$A/F^* - \frac{N_2 \; N' \; c}{(CO_2 + CO + CH_4 + 2C_2H_6) \; C'n}$$

Substituting the numerical values for the constant term gives:

$$A/F^* = 2.58 \; \frac{N_2}{(CO_2 + CO + CH_4 + 2C_2H_6)}$$

I. Air/Fuel ratio by simple orsat - A/F

Assuming that the exhaust gas is composed only of Carbon dioxide, carbon monoxide, oxygen, and Nitrogen, and using the same constants as above.

$$A/F = \frac{2.58 \; N_2}{(CO_2 + CO)}$$

Where N_2 now equals $100 - (CO_2 + CO + O_2)$